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J. Billingsley

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AUSTRALIA

PATENTS ACT 1990

PROVISIONAL SPECIFICATION

FOR THE INVENTION ENTITLED:-

"An Optical Filter, An Optical Interleaver and Associated Methods of Manufacture"

The invention is described in the following statement:-

The present invention relates to an optical filter, an optical interleaver and associated methods of manufacture. The invention has been developed primarily for use in dense wavelength division multiplexing (DWDM) and de-multiplexing in telecommunications applications and will be described hereinafter with reference to this application. However it will be appreciated that the invention is not limited to this particular field of use.

Prior art DWDM's generally fall into two categories, those using an in-fibre Bragg grating, and those utilising thin film coatings, known as narrow band filters. The preferred embodiment of the present invention falls generally into the narrow band filter category.

Some typical prior art narrow band filters are disclosed in U.S. Patent No. 6,008,920, although the bandpass of these filters is generally not as narrow as that of the preferred embodiments of the present invention. Those prior art filters have multiple cavities to square up the bandpass, and each cavity is usually characterised by a centre layer in the form of a thin spacer. The optical thickness of each spacer is a multiple (M) multiplied by half the applicable wavelength, where M is a small integer (typically less than 6, often 1 or 2). In other words, the thickness of each spacer is typically within in the range of approximately 300 nm to 4μm. This allows the spacers to be manufactured by thin film deposition techniques. Figure 1 shows a typical structure for such a filter.

In mass production, prior art narrow band filters are constructed on large area substrates and later sliced and diced into many smaller devices (typically 1-2mm square). To achieve the greatest number of useful devices per batch, the performance of the large area substrate must be very uniform. A major drawback to this technology, particularly as the bandwidth of the filter becomes smaller, is that it becomes more difficult to achieve sufficient uniformity of the layers over the aperture,

and to tightly control the thicknesses of each layer with respect to the others. For these reasons, production yields are typically low, thereby increasing production costs and resulting in a relatively expensive end product.

Fig. 2 shows the predicted spectral transmittance of a typical prior art 50GHz thin film narrow band filter centred at 1550nm. This filter has a passband of 0.28nm when measured as Full Width Half Maximum [or full-width to 3db points]. Figure 5 shows the spectral transmittance of the prior art filter in more detail over the typical wavelength range of an erbium doped fibre amplifier used in many optical telecommunications applications. The layer configuration of this state-of-the-art prior art filter is:

(HL)^10 HHLLL (HL)^20 LLH (HL)^21 H (HL)^10 0.59525H 0.73669L

where H and L refer to quarter-wave optical thickness layers of Ta_2O_5 and SiO_2 (refractive indices 2.065 and 1.465 respectively at 1550nm). The filter consists of 126 layers (bearing in mind that two or more identical "layers" such as HH or LLL are actually counted as one layer) and has a total thickness of about 30μm. The incident medium is air and the substrate glass. This prior art filter has three cavities with three corresponding spacers, each formed by the HH layer. Hence each spacer has an approximate thickness of 380nm (for a narrow band filter centered on 1550nm). Further, each cavity has the a total of approximately 41 thin layers (including the thin layers which together form the spacers).

Typically this prior art filter is used to transmit a narrow passband of marginally less than 0.5nm, which may be centred within the wavelength range of telecommunications equipment such as erbium doped fibre amplifiers and lasers operating between about 1527nm and 1567nm.

The group delay across the passband is an important consideration when assessing the performance of a narrow pass filter. The group delay is proportional to the variation of the phase change on transmission across the pass band. A typical phase change for the prior art filter on transmission over a broad spectral range is illustrated in Figure 3. More particularly, the phase change on transmission over the central pass band wavelength region for the prior art filter is illustrated in Figure 4, with reference to the right hand Y axis. The variation of the phase change is approximately 305° or 1.7π. Also depicted with reference to the left hand Y axis of Figure 4 is the spectral transmittance on transmission over the central pass band wavelength region for the prior art filter.

The effect of uniformity errors of 1 part in 50,000 in the thicknesses of the layers is illustrated in figure 6. In other words, all of the thicknesses of all of the layers are 1.000002 times thicker for the curve shown as a thick line as compared to standard curve without the errors shown as a thin line. Figure 7 illustrates the effect of absorption in all the H layers of the prior art filter corresponding to an extinction coefficient k=0.0001 as the thick curve. Once again, the standard filter performance is illustrated by the thin line for comparative purposes.

Any discussion of the prior art throughout the specification should in no way be considered as an admission that such prior art is widely known or forms part of common general knowledge in the field.

It is an object of the present invention to overcome or ameliorate at least one of the disadvantages of the prior art, or to provide a useful alternative.

Summary of the Invention:

According to a first aspect of the invention there is provided an optical filter having a plurality of cavities, one or more of said cavities including a spacer of thickness greater than 7 μm.

Preferably each spacer defines two opposed surfaces each having a plurality of thin layers disposed thereon, wherein the average number of thin layers per cavity is less than 35. Moreover, in some embodiments the average number of thin layers per cavity is substantially less than 35 and the thickness of each of the spacers is substantially greater than 7μm.

According to a second aspect, the present invention provides an optical filter adapted to receive a dense wavelength division multiplexed optical signal including a plurality of channels ranging in frequency between approximately 1520nm and 1570nm, said filter being adapted to output a single channel of less than 1nm width, said filter having a plurality of cavities, one or more of said cavities including a spacer of thickness greater than 7 μm and wherein said spacer defines two opposed surfaces each having a plurality of thin layers disposed thereon, wherein the average number of thin layers per cavity is less than 35.

According to a third aspect, the present invention provides an optical interleaver having a plurality of cavities, one or more of said cavities including a spacer of thickness greater than 7 μm.

According to a fourth aspect, the present invention provides an optical interleaver adapted to receive a dense wavelength division multiplexed optical input signal including a plurality of channels ranging in frequency between approximately 1520nm and 1570nm, said interleaver being adapted to split said input into an output of at least two sub-sets of channels, wherein each channel has a bandwidth in the range of about 16nm to less than 1nm, said interleaver having a plurality of cavities, one or more of said cavities including a spacer of thickness greater than 7 μm and wherein said spacer defines two opposed surfaces each having a plurality of thin layers disposed thereon, wherein the average number of thin layers per cavity is less than 35.

According to a fifth aspect, the present invention provides a method of manufacturing an optical filter as described above, said method including the steps of:

producing a plurality of spacers by optically polishing a substrate, wherein at least one of said spacers has a thickness of greater than 7μm;

using thin film deposition to deposit a plurality of thin layers onto each of said spacers to form cavities, whereby the average number of thin layers per cavity is less than 35; and

optically contacting said plurality of cavities to form said filter.

According to a sixth aspect, the present invention provides a method of manufacturing an optical filter as described above, said method including the steps of:

a) utilising thick film deposition to produce a spacer having a thickness of greater than 7μm;

b) utilising thin film deposition to deposit a plurality of thin layers onto said spacer to form a cavity, the average number of thin layers per cavity being less than 35;

c) repeating combinations of steps a) and b) so as to form said filter.

According to a seventh aspect, the present invention provides a method of manufacturing an optical interleaver as described above, said method including the steps of:

producing a plurality of spacers by optically polishing a substrate, wherein at least one of said spacers has a thickness of greater than 7μm;

using thin film deposition to deposit a plurality of thin layers onto each of said spacers to form cavities, whereby the average number of thin layers per cavity is less than 35; and

optically contacting said plurality of cavities to form said interleaver.

According to another aspect, the present invention provides a method of manufacturing an optical interleaver as described above, said method including the steps of:

a) utilising thick film deposition to produce a spacer having a thickness of greater than 7μm;

b) utilising thin film deposition to deposit a plurality of thin layers onto said spacer to form a cavity, the average number of thin layers per cavity being less than 35;

c) repeating combinations of steps a) and b) so as to form said interleaver.

Preferred embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a schematic diagram depicting a typical narrow band filter according to the prior art;

Figures 2 to 7 are graphs illustrating various performance characteristics of a typical example of the prior art filter according to figure 1, as described in more detail in the above discussion of the prior art;

Figures 8, 9 and 10 are graphs of the spectral transmittance of an output provided by a first embodiment of the present invention as compared to the prior art mentioned above;

Figure 11 is a graph showing both the spectral transmittance and the phase change of an output provided by a first embodiment of the present invention as compared to the prior art mentioned above;

Figure 12 is a graph showing the effects of an absolute error of .053nm in spacer thickness to the output provided by a first embodiment of the present invention;

Figure 13 is a graph showing the effects of an extinction coefficient of k=0.0001 in all of the H layers of the prior art mentioned above;

Figures 14 and 15 are graphs of the spectral transmittance of an output provided by a second embodiment of the present invention as compared to the prior art mentioned above;

Figures 16 and 17 are graphs of the spectral transmittance of an output provided by a third embodiment of the present invention as compared to the prior art mentioned above;

Figure 18 is a graph showing the effect of an absolute error of 1.6nm in the spacer thickness for the third embodiment of the invention;

Figure 19 is a graph of the spectral transmittance of an output provided by a fourth embodiment of the present invention;

Figure 20 is a graph showing both the spectral transmittance and the phase change of an output provided by the fourth embodiment of the present invention;

Figure 21 is a graph showing the effects of an error in the thickness of the thin film layers in the fourth embodiment of 3 parts per 1000;

Figure 22 is a graph of the spectral transmittance of an output provided by a fourth embodiment of the present invention;

Figures 23 and 24 are graphs of the spectral transmittance of an output provided by a fifth embodiment of the present invention;

Figure 25 is a graph showing the effects of nonuniformity errors in the spacer thickness of the fifth embodiment;

Figures 26 and 27 are schematic diagrams illustrating the functioning of networks of preferred embodiments of interleavers according to the present invention;

Figures 28 and 29 are graphs of the spectral transmittance of outputs provided by a preferred embodiment of an interleaver according to the present invention;

Figure 30 is a graph showing the effects of nonuniformity errors in the thin layers of the preferred embodiment of an interleaver according to the present invention;

Figure 31 is a graph showing the effects of nonuniformity errors in the spacers of the preferred embodiment of an interleaver according to the present invention; and

Figures 32 and 33 are illustrations of the first embodiment of a filter according to the invention.

First Preferred Embodiment of the Optical Filter:

The first preferred optical filter 1 according to the present invention is illustrated in figures 32 and 33 which are not to scale. The filter 1 is adapted to receive a dense wavelength division multiplexed optical signal 2 as an input. The signal 2 includes a plurality of channels ranging in frequency within a predetermined frequency range. Preferably the range is between approximately 1520nm and 1570nm, with 1527nm to 1567nm being the range utilised in the first preferred embodiment. The filter 1 is adapted to output a single channel 3 of less than 1nm bandwidth. In other words, this filter allows a single channel to be extracted from a

previously multiplexed signal. The filter 1 has a plurality of cavities 4 which are each optically connected to an adjacent cavity 4 by means of a coupling layer 8.

Preferably one or more of the cavities include a spacer 5 of thickness greater than 7μm. In the first embodiment as illustrated each of the cavities 4 has a spacer 5 of 21μm thickness. Other embodiments (not illustrated) have spacer thickness ranging between 7μm up to greater than 1.5mm. For example, some embodiments have spacer thicknesses of greater than: 10 μm, 20 μm, 50 μm, 100 μm, etc.

Each spacer 5 defines two opposed surfaces 6 each having a plurality of thin layers 7 disposed thereon. Preferably the average number of thin layers 7 per cavity 4 is less than 35 and in the illustrated embodiment the number of thin layers 7 per cavity 4 is 26. Other embodiments (not illustrated) have average numbers of thin layers 7 per cavity 4 of less than: 30, 25, 15, etc. The exact details as to the spacer thickness and number of thin layers per cavity will vary depending upon the particular function to be performed by the filter. For example, some embodiments of the invention (not illustrated) are engineered to provide a passband of less than 5nm. Other embodiments have passbands of less than 1nm or 0.5nm. The illustrated embodiment has a passband of 0.28nm centred at 1550nm which is essentially identical to the state-of-the-art prior art filter mentioned above.

It can be seen from figures 8, 9, 10 and 11 that the performance of the first embodiment of the invention (shown as a thick line on the graphs) very closely matches the performance of the state-of-the-art prior art filter mentioned above (shown as the thin line). The spectral performance of the first embodiment and the prior art are compared over a broad bandwidth in figure 8. As attenuations of approximately 40db are usually considered sufficient, the minor discrepancies between the two curves at attenuations of less than 100db are functionally irrelevant. Figure 9 shows that over a bandwidth of 1548nm to 1552nm the first embodiment

almost perfectly matches the spectral performance of the prior art. Figure 10 focuses more closely on the relative performances of the invention and the prior art over the central passband region. Once again, the two curves are closely matched. It can be seen from figure 11 that the two filters exhibit very similar variations in phase change on transmission across the passband. Hence the group delay of the two designs is very similar.

Advantageously however, the filter according to the first preferred embodiment requires significantly less thin layers as compared to the prior art mentioned above. Additionally, the first preferred embodiment may be manufactured with significantly relaxed tolerances as compared to the prior art in relation to parameters such as the thin layer uniformity and the acceptable degree of absorption. This is confirmed by figures 12 and 13. The effect of an increase in the relative thicknesses due to non-uniformity in thin layers of 4 parts in 10,000 is illustrated in figure 12. The normal curve is shown as the thin line and the thick line shows the effects of the error. Figure 12 may be compared to the effects caused in the prior art by an error in thin layer thickness of 1 part in 50,000 as illustrated in figure 6. The first embodiment is roughly 20 times less sensitive to errors in thin layer uniformity as the prior art filter mentioned above. Figure 13 shows the effect of an extinction coefficient of $k=1 \times 10^{-4}$ for the first embodiment (thick line) as compared to the prior art mentioned above (thin line). It can be seen that the first embodiment is roughly ten times as tolerant to absorption as the prior art mentioned above.

Advantageously the first embodiment of the present invention is also tolerant to minor errors in the spacer thickness. The same effects as illustrated in figure 12 are caused by an absolute error of 0.53nm in the spacer thickness.

The significantly relaxed tolerances of the first embodiment of the present invention allow the filter to be produced at a reduced cost. It also allows for increased yields for each product run. More particularly:

- The maximum allowable uniformity error in the thickness of each of said thin layers is preferably within the range of 1 part in 50,000 to 4 parts in 10,000. 18.
- The maximum allowable absorption in each of said thin layers preferably corresponds to an extinction coefficient of between 1×10^{-4} and 1×10^{-5}.
- The maximum allowable uniformity error in the thickness of each of said spacers is preferably less than or equal to 0.53nm.

Preferably at least one of the cavities is formed in accordance with the following formula:

(HL)^6 HMH (LH)^6

where H is a quarter wavelength layer of material having a refractive index of approximately 2.065, L is a quarter wavelength layer of material having a refractive index of approximately 1.465 and M is a spacer of approximately 21µm thickness and having an approximate refractive index of 1.465.

Indeed, in the first embodiment of a filter according to the invention each of the cavities is formed in accordance with the above formula. Hence, the filter as a whole is given by:

((HL)^6 HMH (LH)^6 L)^3

where H, L and M are as defined above and the final L layer on the right hand side of the formula acts as the coupling layer. The thin H layers are constructed from Ta_2O_5. The thin L layers, along with the spacers, are constructed from SiO_2. Of course, it will be appreciated by those skilled in the art that other materials, having different refractive indices, may be employed provided appropriate changes are made to the design of the filter.

The total thickness of the first embodiment is 82μm, each spacer being 21μm thick and each 13 layer reflective stack {that is (HL)^6 H } is 3μm thick. There is an average of approximately 26 layers per cavity in this embodiment.

Second Preferred Embodiment of the Optical Filter:

In the second embodiment of the invention (not illustrated) at least one of the cavities is formed in accordance with the following formula:

(HL)^4 HMH (LH)^4

where H and L are defined as for the first embodiment and M is a spacer of approximately 106μm thickness and having an approximate refractive index of 1.465. The spacer in this embodiment is roughly five times thicker than that in the first embodiment.

The second embodiment of the optical filter is in accordance with the following formula:

((HL)^4 HMH (LH)^4 L)^3.

The spectral performance of the second embodiment of the invention over the band width of interest is illustrated in figure 14. It can be seen that unwanted adjacent side orders 9 are allowed to pass through this filter. Hence the second embodiment of the optical filter is preferably used in combination with a blocking filter having a passband of approximately 12nm so as to block unwanted adjacent side orders 9.

The tolerances of this embodiment of the invention may be relaxed to a degree greater than those of the first embodiment:

- The maximum allowable uniformity error in the thickness of each of said thin layers may fall within the range of 1 part in 50,000 to 3 parts in 2,000.
- The maximum allowable uniformity error in the thickness of each of said the spacers is preferably less than or equal to 3.09nm.

The second embodiment of the invention has a passband of approximately the same width as the first embodiment, along with a similar group delay. This

embodiment has a total thickness of 330μm, each spacer being 106μm thick and each 9 layer reflecting stack {that is (HL)^4 H} being about 2μm thick. There is an average of approximately 18 thin layers per cavity in this embodiment.

Third Preferred Embodiment of the Optical Filter:

In the third preferred embodiment of the optical filter at least one of the cavities is formed in accordance with the following formula:

(HL)^4 HMH (LH)^4

where H and L are defined as above and M is a spacer of approximately 529μm thickness and having an approximate refractive index of 1.465.

The optical filter of the third embodiment is in accordance with the following formula:

((HL)^4 HMH (LH)^4 L)^3.

As may be seen from figure 16, unwanted adjacent side orders 9 are allowed to pass through this filter. Hence this embodiment may be used in combination with a blocking filter having a passband of approximately 2.4nm so as to block adjacent side orders.

Tolerances for the third embodiment are:

- The maximum allowable uniformity error in the thickness of each of said thin layers is within the range of 1 part in 50,000 to 1.2 parts in 1,000.
- The maximum allowable uniformity error in the thickness of each of said spacers is less than or equal to 1.6nm.

The third embodiment has a passband of less than 0.05nm which is narrower than the prior art narrow band thin film filters known to the inventor. It has a total thickness of 1.6mm, with each spacer being 529μm. Each 9 layer reflecting stack {that is (HL)^4 H} has a thickness of about 2μm. The average number of thin layers per cavity is approximately 18.

Fourth Preferred Embodiment of the Optical Filter:

The layer configuration for the fourth embodiment is in accordance with the following formula:

(HL)^2 HMH (LH)^2 L ((HL)^3 HMH (LH)^3 L)^2 (HL)^2 HMH (LH)^2

where H and L are defined as above and M is a spacer of approximately 1.32mm thickness and having an approximate refractive index of 1.465.

This embodiment is easier to manufacture than the first, second and third embodiments, however is only suitable for applications where a high group delay is acceptable. It can be seen from figure 19 that the passband is similar to that of the third embodiment. However, figure 20 shows that the variation of the phase change on transmission across the passband is greater that that of the previous embodiments.

It is preferable to use the fourth embodiment in combination with a blocking filter having a passband of approximately 1nm so as to block adjacent side orders. The tolerances for this embodiment are further relaced as follows:

- The maximum allowable uniformity error in the thickness of each of said thin layers is within the range of 1 part in 50,000 to 3 parts in 1,000.
- The maximum allowable uniformity error in the thickness of each of said spacers is less than or equal to 3.96nm.

The total thickness of the thin layers in the fourth embodiment is 11.5μm, with each spacer being 1.32mm.

Each of the first four embodiments of the filter show that performance roughly equal to, or better than, the state-of-the-art prior art mentioned above can be achieved by the invention, however with far more relaxed tolerances and lesser number of thin layers. The next embodiment shows that if tolerances approaching those of the prior art are utilised, along with a greater number of thin layers, then performance far exceeding the state-of-the-art may be achieved.

Fifth Preferred Embodiment of the Optical Filter:

The fifth embodiment is in accordance with the following formula:

((HL)^7 HMH (LH)^7 L) ((HL)^8 HMH (LH)^8 L)^2 ((HL)^7 HMH (LH)^7)

where H and L are defined as above and M is a spacer of approximately 0.8mm thickness and having an approximate refractive index of 1.465.

Tolerances for this embodiment are:

- The maximum allowable uniformity error in the thickness of each of said thin layers is within the range of 1 part in 50,000 to 1 part in 10,000.
- the maximum allowable uniformity error in the thickness of each of said spacers is less than or equal to 0.11nm.

The fifth embodiment of the optical filter has a passband of approximately 0.002nm. This is radically smaller than any prior art known to the inventor as at the priority date. A 0.02nm wavelength passband is equivalent to a 0.2GHz frequency passband. The prior art filters having a passband of around 0.5nm allow for approximately 40 to 80 channels. If other telecommunications equipment were sufficiently upgraded so as to support this embodiment of the invention, it would theoretically allow for a single channel to be extracted from a multiplexed input having approximately 15000 channels across a 30nm bandwidth. This improvement in performance would allow the information carrying capacity of currently laid optical fibres to be dramatically increased, thereby helping to address the rapidly growing world wide demand for digital telecommunications, for example due to increases in Internet usage.

Preferred Methods for Manufacturing Filters According to the Invention:

A first preferred method of manufacturing an optical filter 1 in accordance with the invention includes the steps of:

producing a plurality of spacers 5 by optically polishing a substrate, wherein at least one of said spacers 5 has a thickness of greater than 7μm;

using thin film deposition to deposit a plurality of thin layers 7 onto each of said spacers 5 to form cavities 4, whereby the average number of thin layers 7 per cavity 4 is less than 35; and

optically contacting said plurality of cavities 4 to form said filter 1.

It will be appreciated that the spacer thicknesses tolerances required for manufacture of the preferred embodiments of the optical filter are within the capabilities of those skilled in the art of optical polishing. Similarly, the required thin layer tolerances are within the capabilities of those skilled in the art of thin film deposition.

The second preferred method of manufacturing an optical filter 1 in accordance with the invention includes the steps of:

a) utilising thick film deposition to produce a spacer 5 having a thickness of greater than 7μm;

b) utilising thin film deposition to deposit a plurality of thin layers 7 onto said spacer 5 to form a cavity 4, the average number of thin layers 7 per cavity 4 being less than 35;

c) repeating combinations of steps a) and b) so as to form said filter 1.

In the exemplary preferred embodiments described above the spacer is made of SiO_2, a material with a relatively low refractive index in comparison to many other transparent materials at the wavelength range of interest (about 1550nm). This type of filter is appropriate for applications which are tolerant of a high sensitivity to wavelength shift as a function of tilting with respect to the angle of incidence of the incident radiation. If such sensitivity is to be avoided, it is preferable to choose a spacer material with a higher refractive index, such as silicon. An additional advantage of using such a material is that it is more amenable to the second preferred method for manufacturing the filters which preferably uses automated equipment and procedures similar to those used in semiconductor fabrication

technology. In yet further embodiments, various other crystalline and amorphous bulk materials are also used to make suitable spaces.

Preferred Embodiment of An Optical Interleaver:

Optical interleavers are adapted to receive a dense wavelength division multiplexed optical input signal including a plurality of channels within a predetermined frequency range and to split said input into an output of at least two sub-sets of channels. For example, an interleaver may divide the channels into odd and even sets, or into an upper half and a lower half. Often channels are separated such that some channels are reflected by the interleaver and others are transmitted through the interleaver.

As is known from the prior art, a network of interleavers may be utilised to separate all of the channels from a multiplexed input signal. Examples of such networks are illustrated in figures 26 and 27. Each of the interleavers 9 of the network in figure 26 split the input signal into upper and lower halves. Each of the interleavers 10 of the network in figure 27 split the input signal into alternate odd and even channels.

The preferred embodiment of the interleaver has a plurality of cavities, one or more of the cavities including a spacer of thickness greater than 7 μm. Each spacer defines two opposed surfaces each having a plurality of thin layers disposed thereon, wherein the average number of thin layers per cavity is less than 35. Other embodiments of the interleaver have an average number of thin layers per cavity is less than 30, 25, 15 or 10. The thickness of the spacer is preferably greater than 10 μm, although in other embodiments it is greater than 20 μm, 50 μm or 100 μm. Each of the channels separated by the preferred embodiment preferably has a bandwidth of less than 5μm, although some preferred embodiments are capable of separating channels of less than 1μm or 0.5μm. The predetermined frequency range

within which the channels of the input signal are multiplexed is typically approximately 1520nm to 1570nm for telecommunications, although other ranges may be employed for various applications.

At least one of the cavities of the preferred embodiment is formed in accordance with the following formula:

HLHM

where H is a quarter wavelength layer of material having a refractive index of approximately 2.065, L is a quarter wavelength layer of material having a refractive index of approximately 1.465 and M is a spacer of approximately 0.8mm thickness and having an approximate refractive index of 1.465.

More particularly, the overall preferred interleaver is formed in accordance with the following formula:

(HLHM)^10 HLH

This is a 10-cavity filter which is preferably optimised to reduce ripple. In the preferred embodiment each of the H layers is constructed from Ta_2O_5, and the L layers are constructed from SiO_2. The 0.8mm thick M layers, that is the spacers, are also constructed from SiO_2. The total thickness of the interleaver is approximately 8mm, consisting of a total of 41 layers (optimised down from the starting design of 43 layers, 3 S 3 S 3 S...). There are 10 high order thick layers and 31 $\lambda/4$ layers.

Figures 28 and 29 show the spectral transmittance and reflectance respectively of the preferred embodiment. It can be seen that the preferred embodiment divides the input signal into alternate odd and even channels.

As was the case for the filter described above, the tolerances for the interleaver are relatively relaxed compared to the prior art. The maximum allowable uniformity error in the thickness of each of said thin layers is preferably equal to or less than 5nm. The maximum allowable uniformity error in the thickness of each of

said spacers is equal to or less than 8nm. Figures 30 and 31 show the effects of these errors respectively.

Preferred Methods for Manufacturing Interleavers According to the Invention:

A first preferred method of manufacturing an optical interleaver as described above includes the steps of:

producing a plurality of spacers by optically polishing a substrate, wherein at least one of said spacers has a thickness of greater than 7μm;

using thin film deposition to deposit a plurality of thin layers onto each of said spacers to form cavities, whereby the average number of thin layers per cavity is less than 35; and

optically contacting said plurality of cavities to form said interleaver.

An alternative preferred method of manufacturing an optical filter as described above includes the steps of:

a) utilising thick film deposition to produce a spacer having a thickness of greater than 7μm;

b) utilising thin film deposition to deposit a plurality of thin layers onto said spacer to form a cavity, the average number of thin layers per cavity being less than 35; and

c) repeating combinations of steps a) and b) so as to form said interleaver.

Although the invention has been described with reference to specific examples, it will be appreciated by those skilled in the art that it may be embodied in many other forms.

DATED this 14th Day of July 2003
BALDWIN SHELSTON WATERS
Attorneys for:
Commonwealth Scientific and Industrial Research Organisation

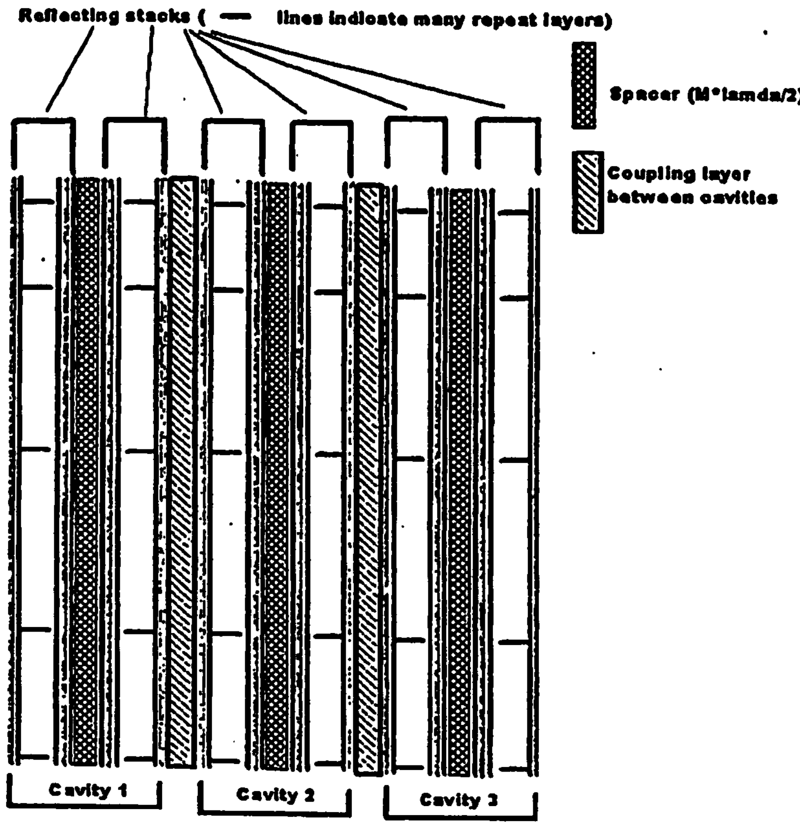


Figure 1 (Prior Art Filter)

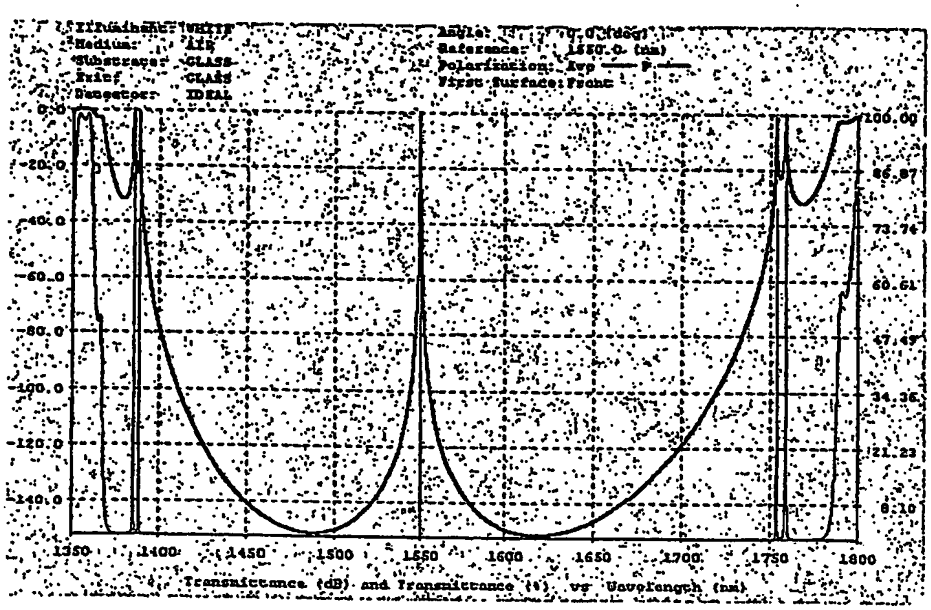


Figure 2 (Spectral Transmittance of Prior Art Filter)

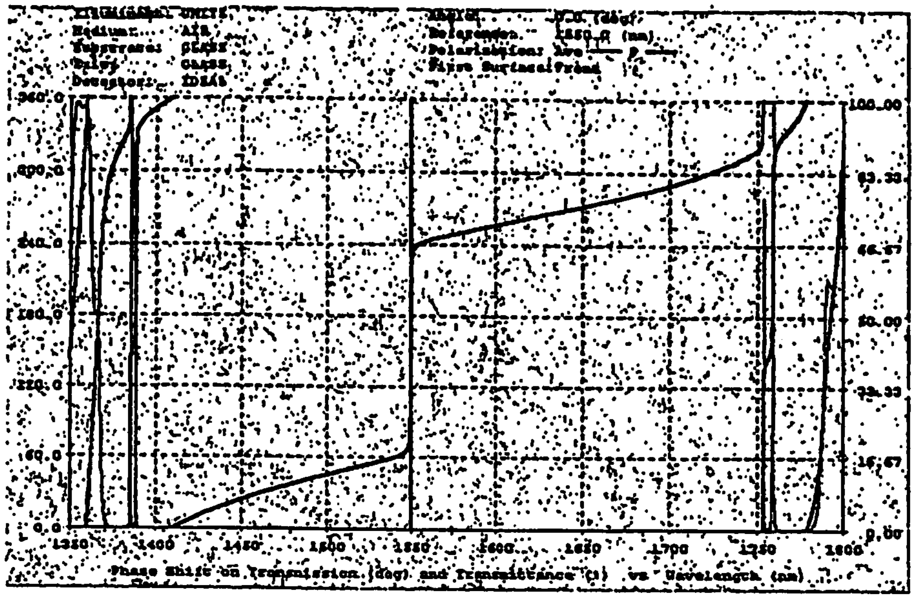


Figure 3 (Prior Art Phase Change)

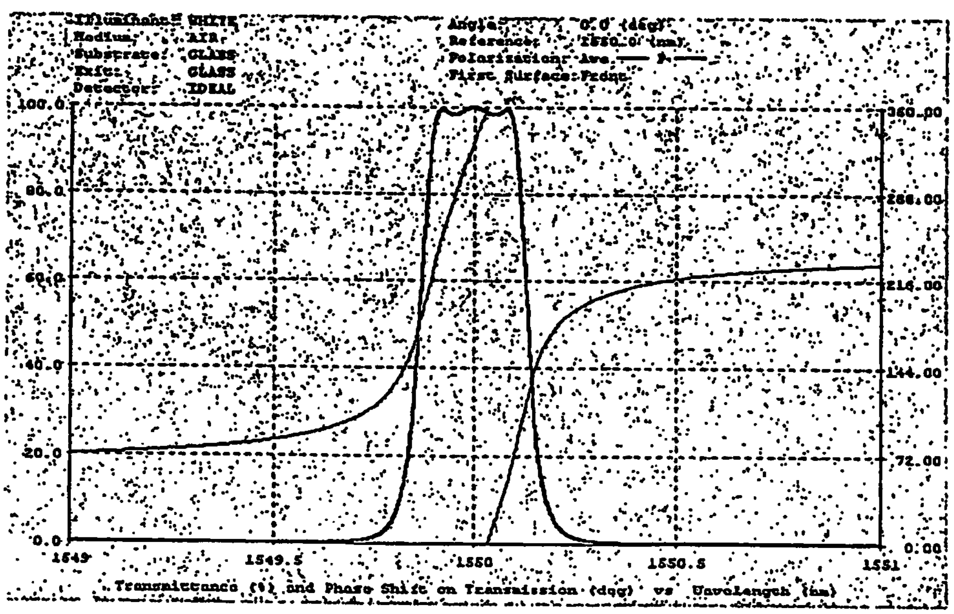


Figure 4 (Prior Art Phase Change)

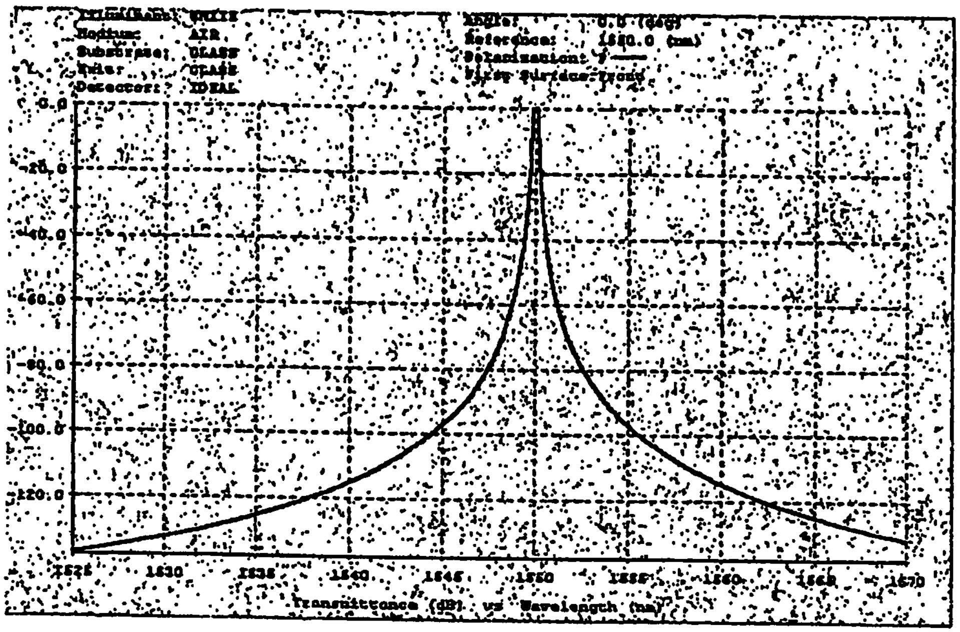


Figure 5 (Spectral Transmittance of Prior Art Filter)

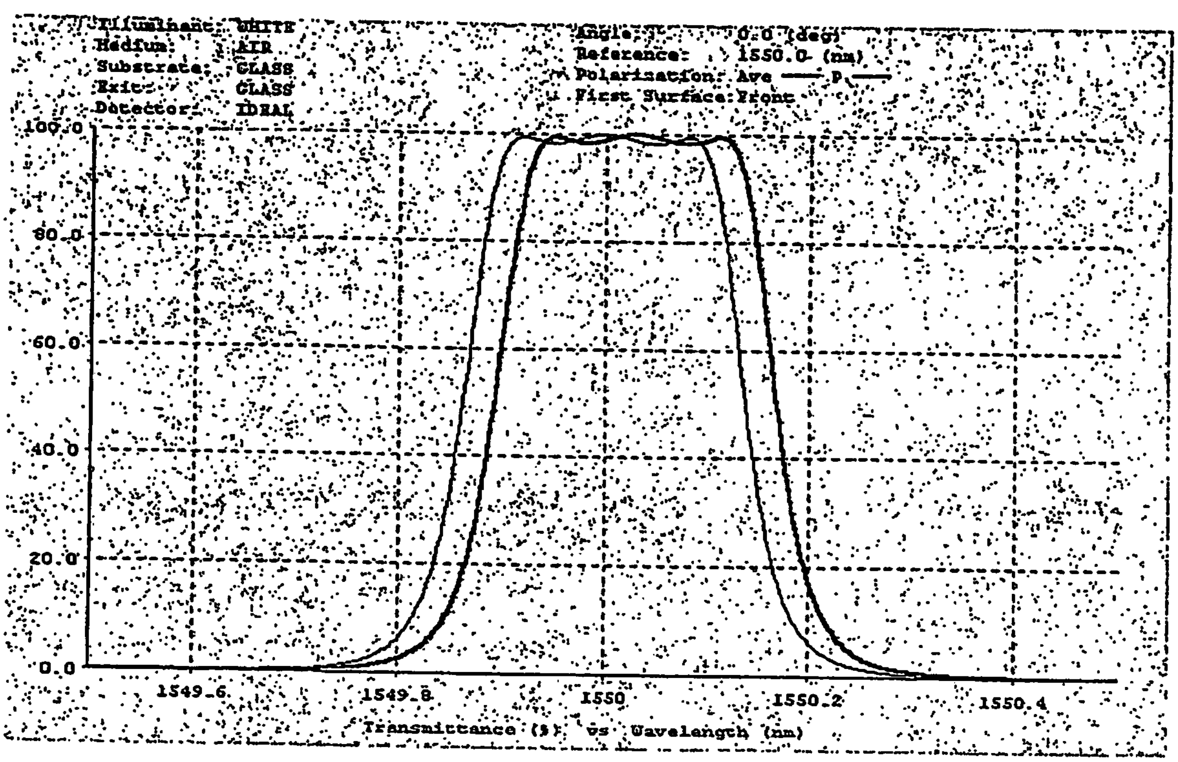


Figure 6 (Spectral Transmittance of Prior Art Filter including error effects)

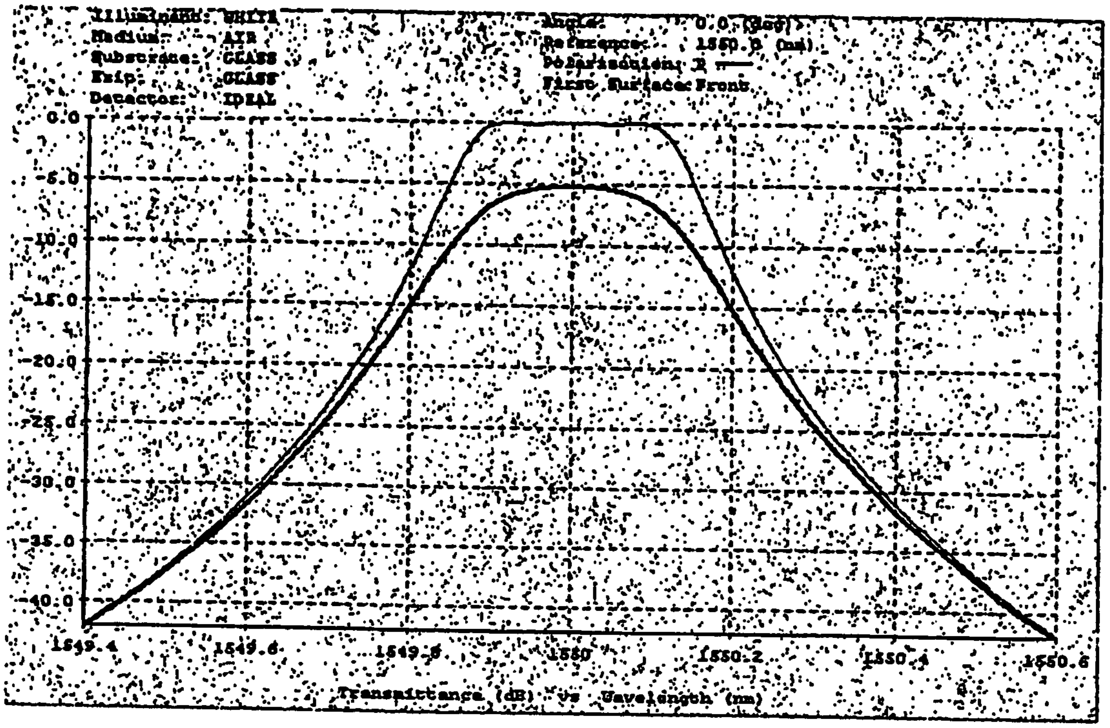


Figure 7 (Spectral Transmittance of Prior Art Filter including error effects)

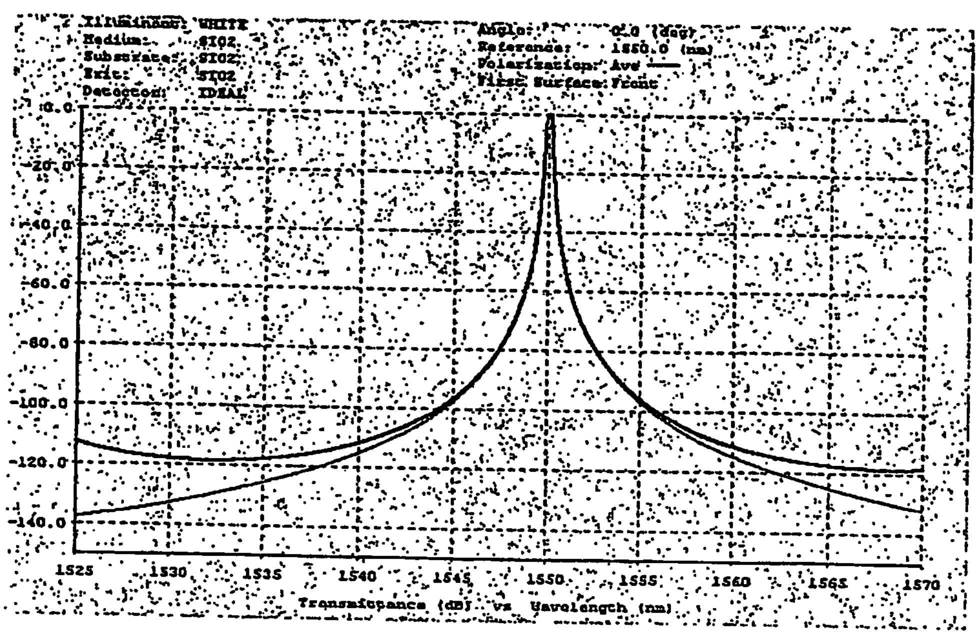


Figure 8

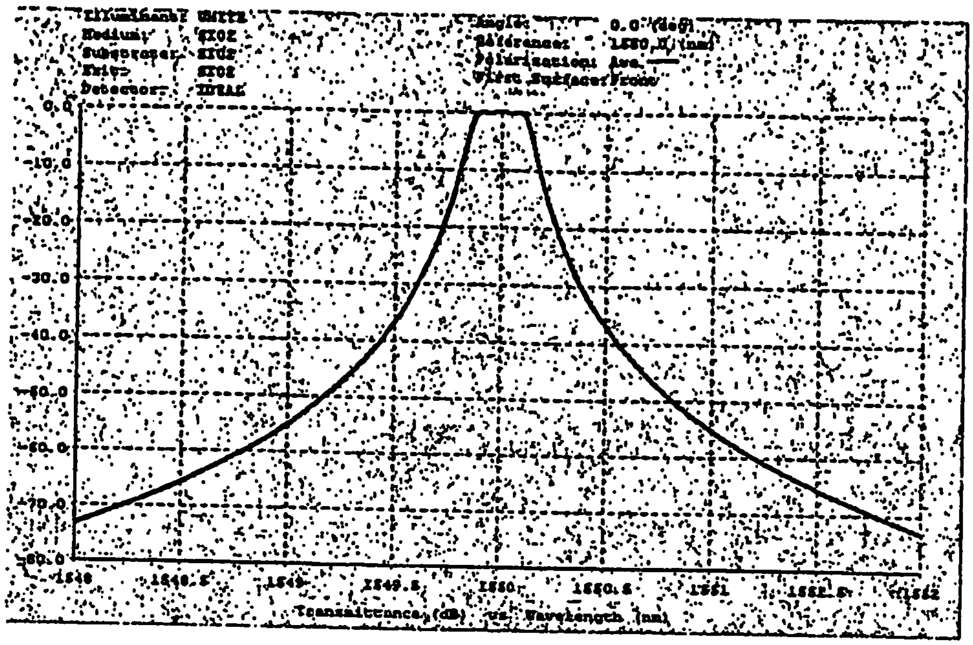


Figure 9

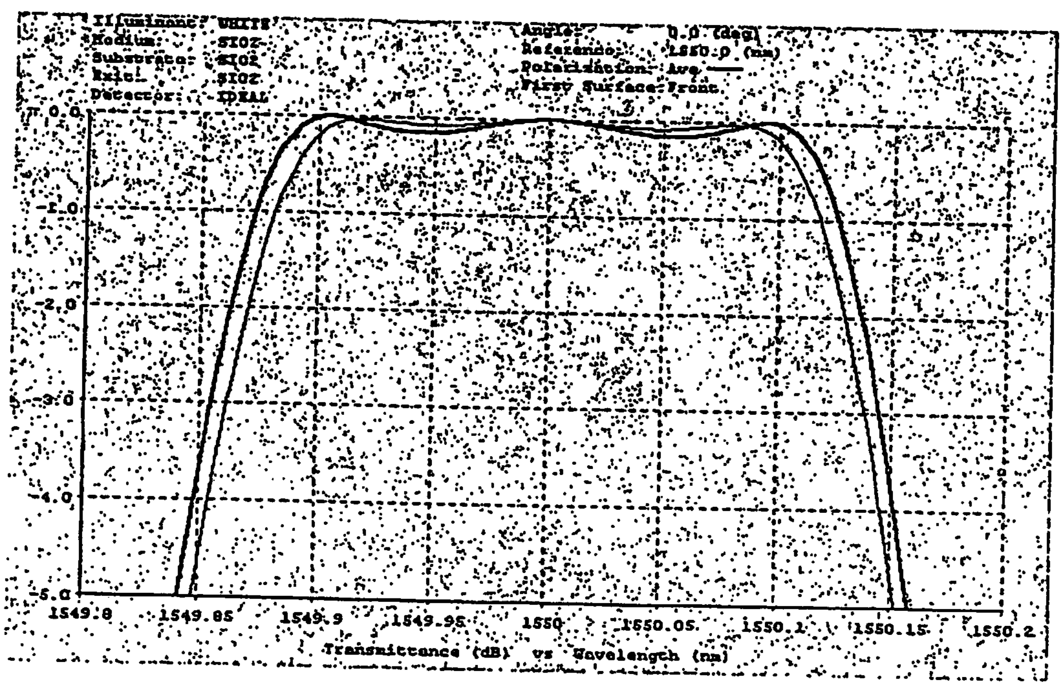


Figure 10

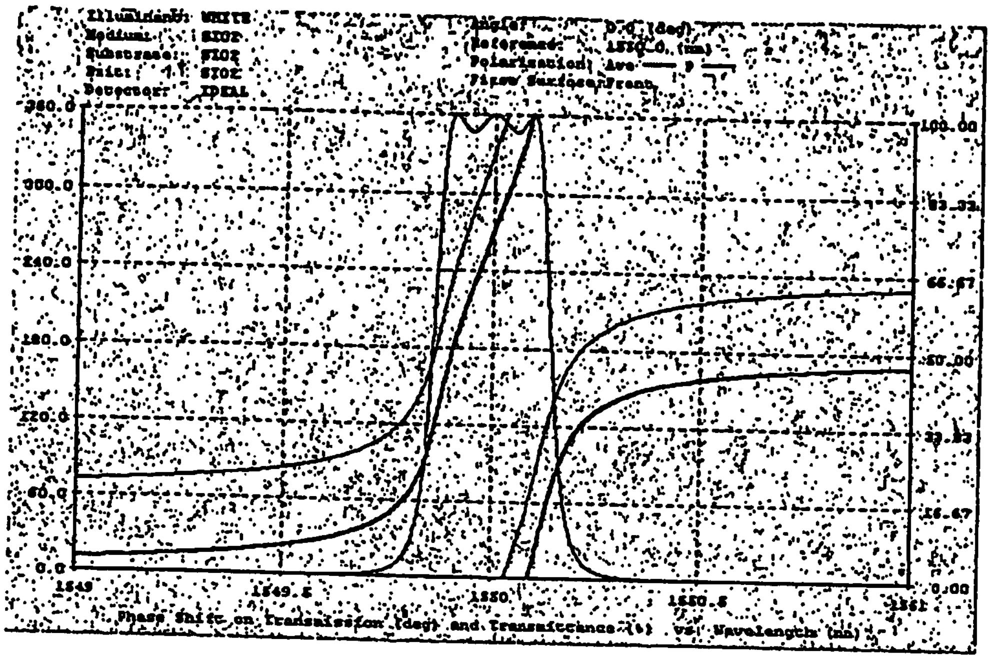
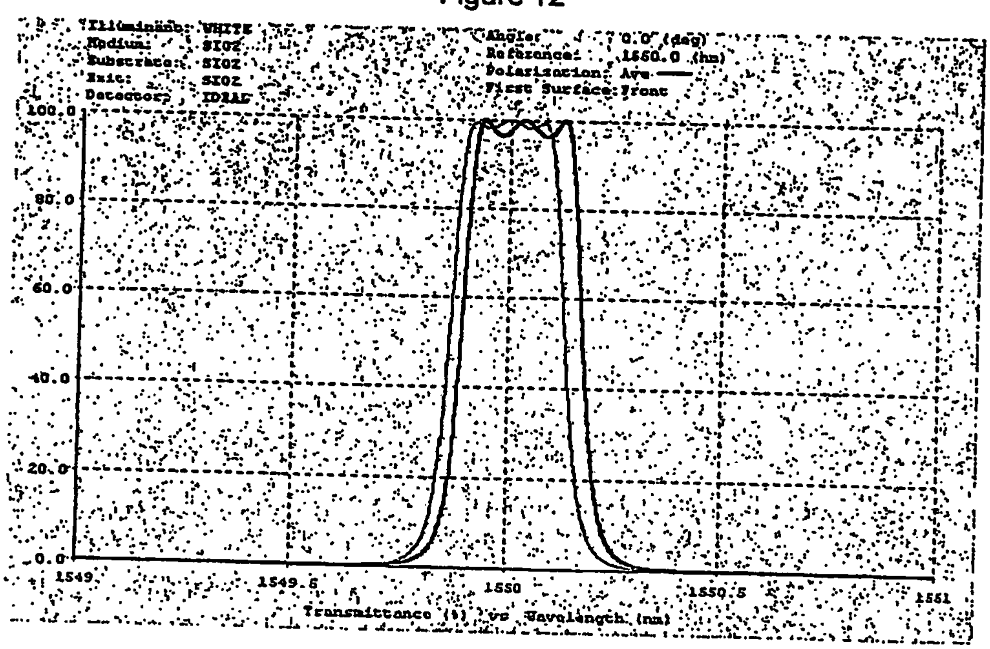


Figure 11

Figure 12



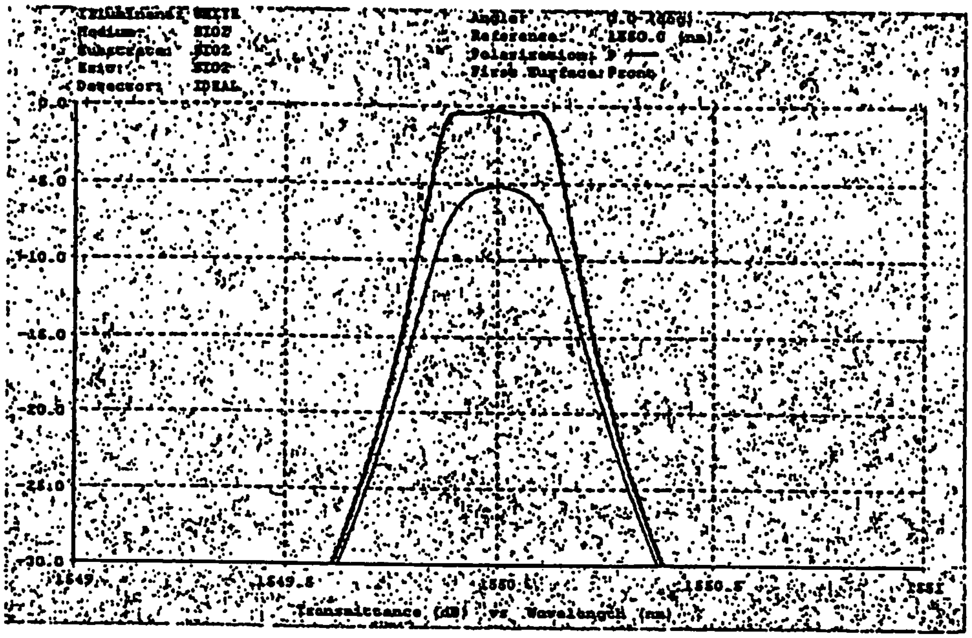


Figure 13

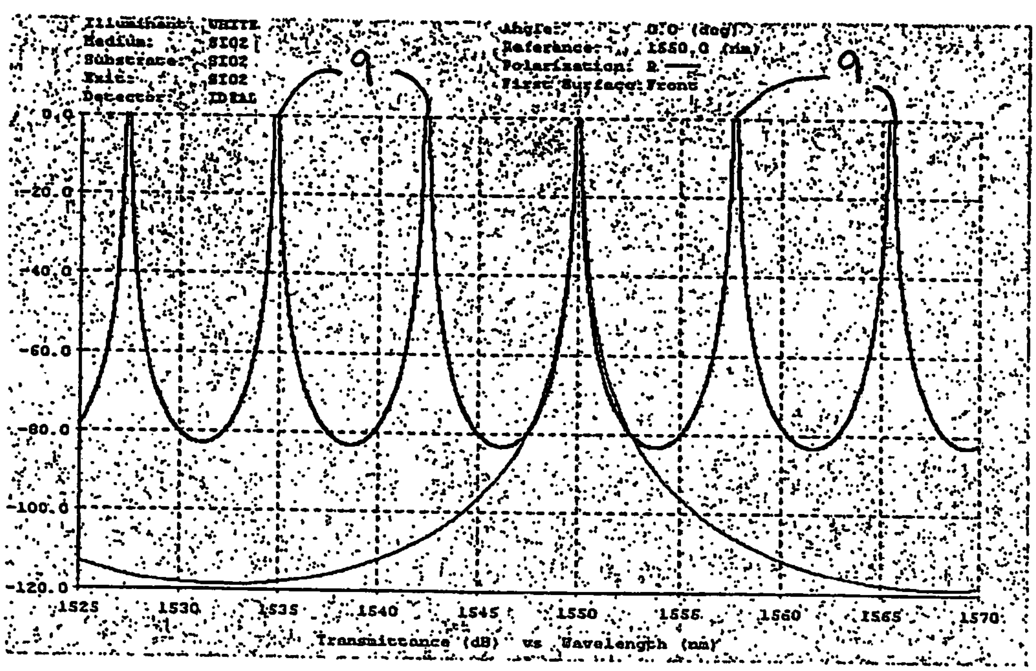


Figure 14

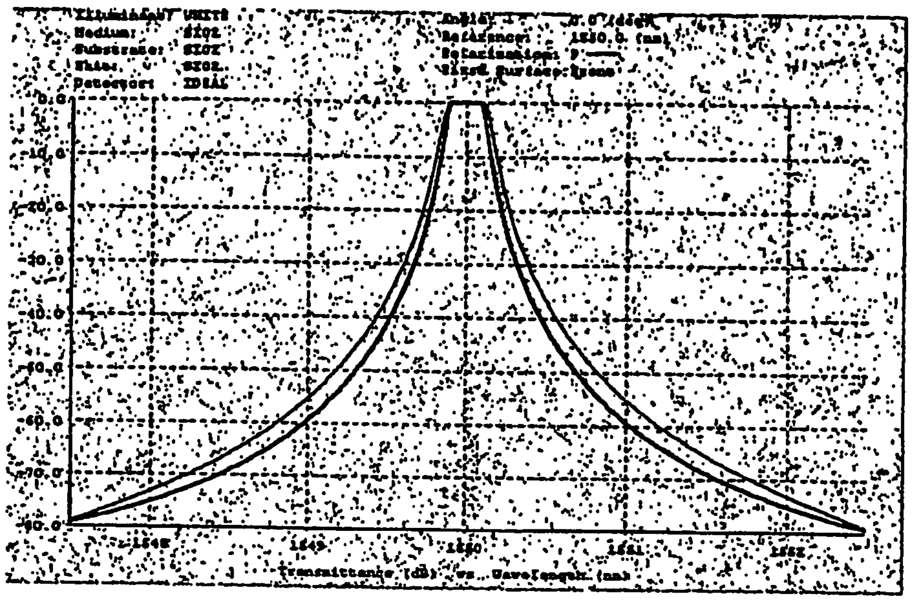


Figure 15

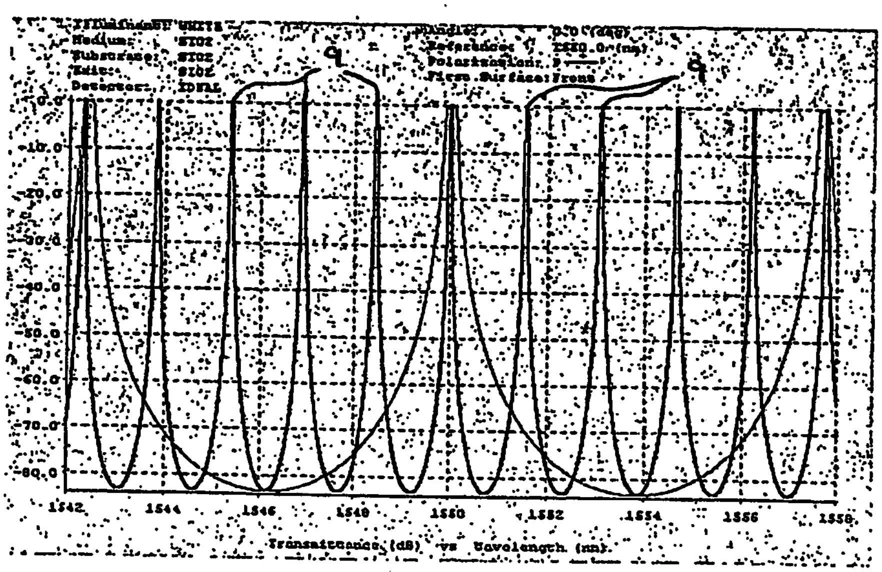


Figure 16

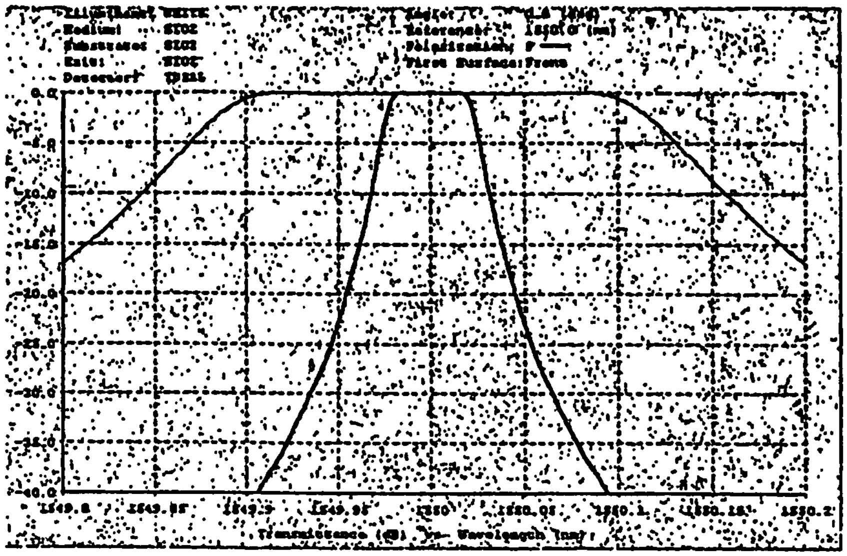


Figure 17

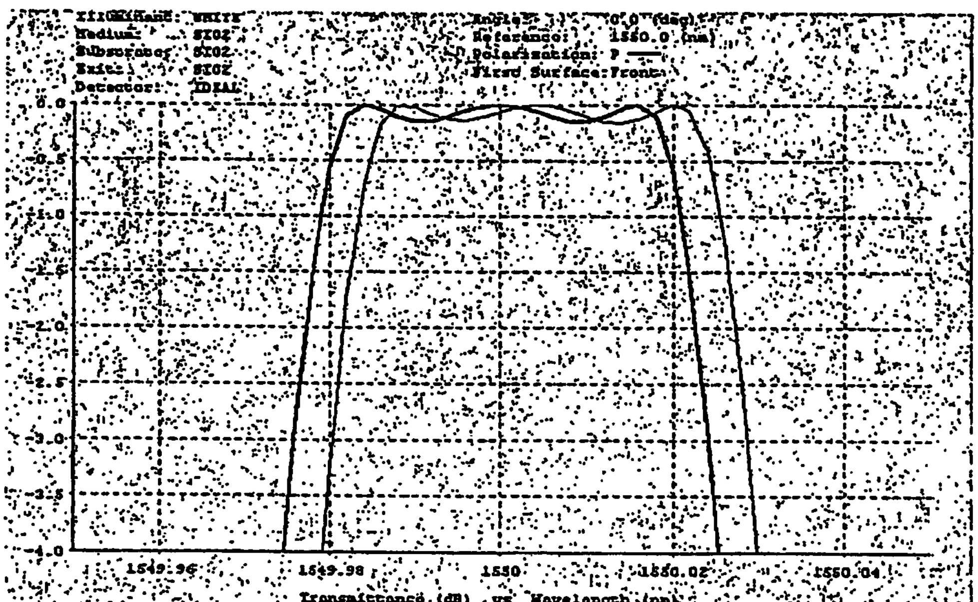


Figure 18

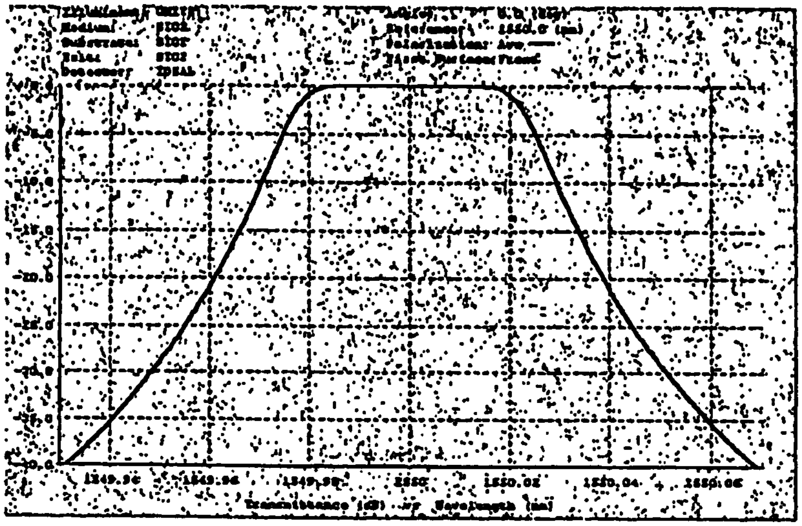


Figure 19

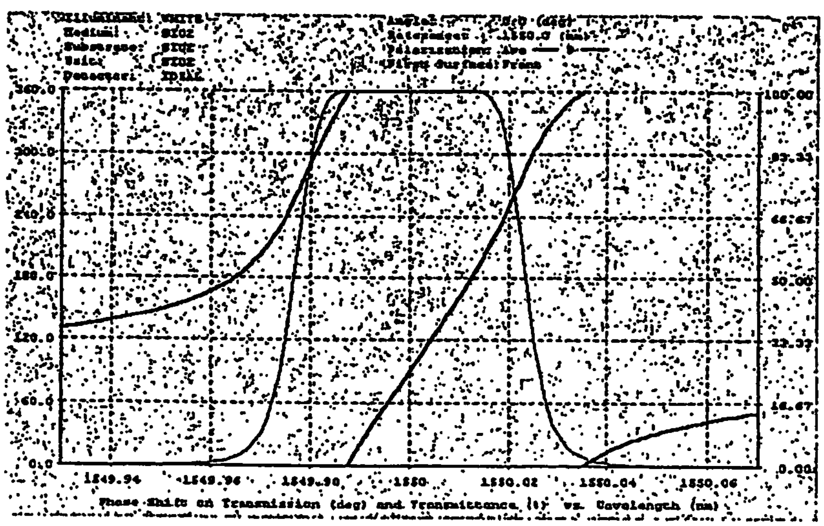


Figure 20

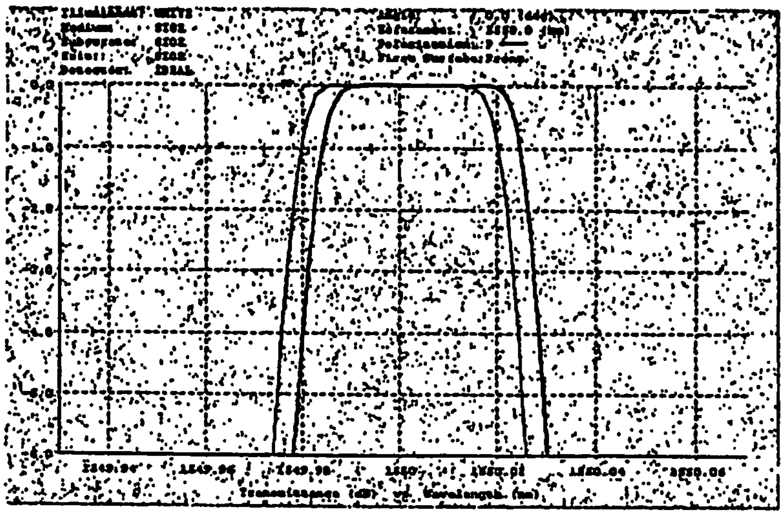


Figure 21

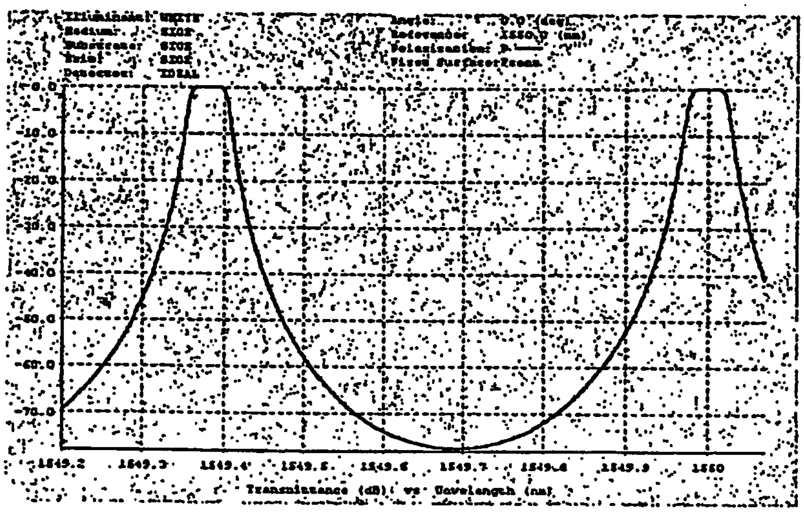


Figure 22

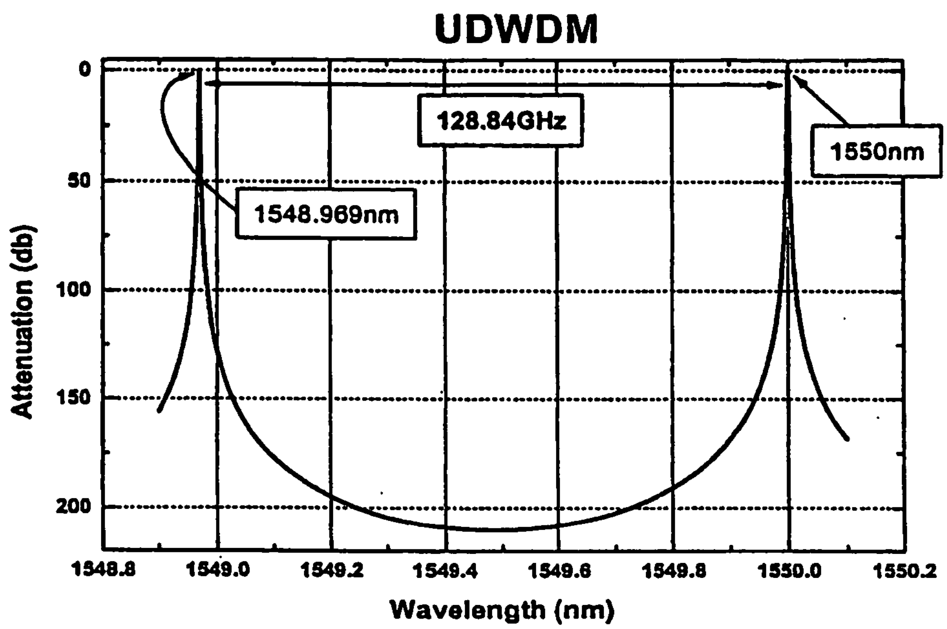


Figure 23

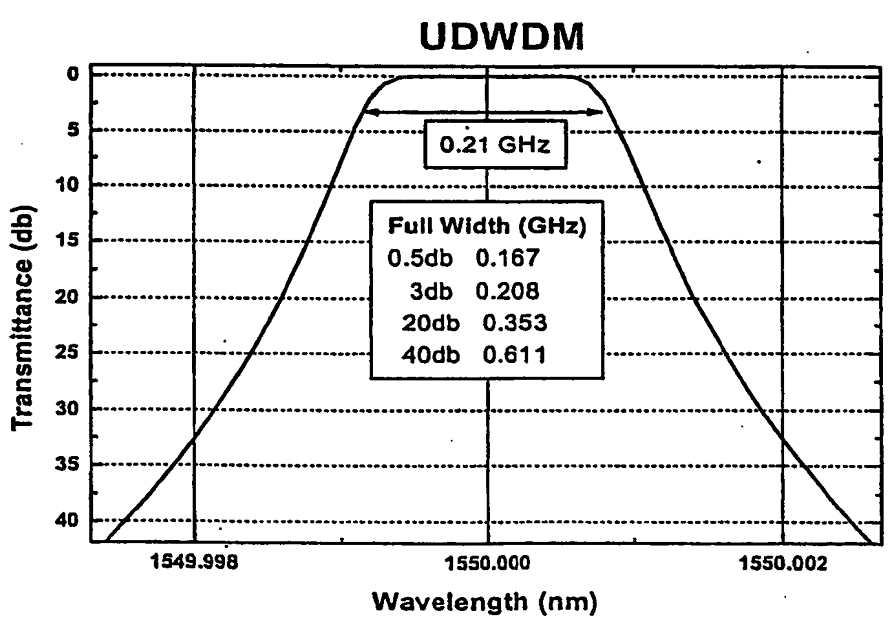


Figure 24

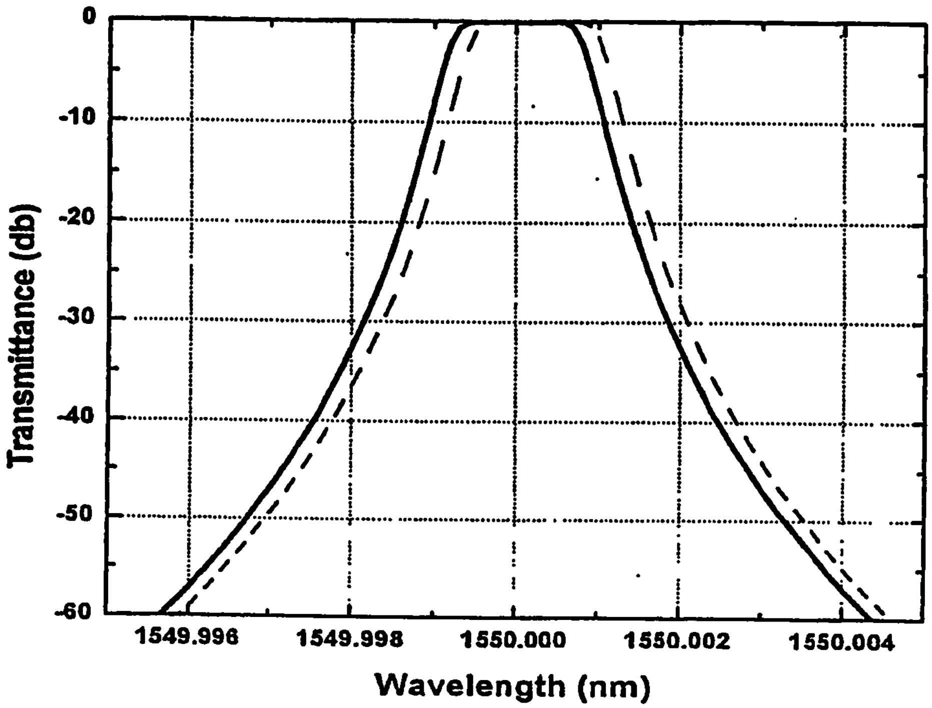

0
-10
-20
-30
-40
-50
-60
Transmittance (db)
1549.996
1549.998
1550.000
1550.002
1550.004
Wavelength (nm)

Figure 25

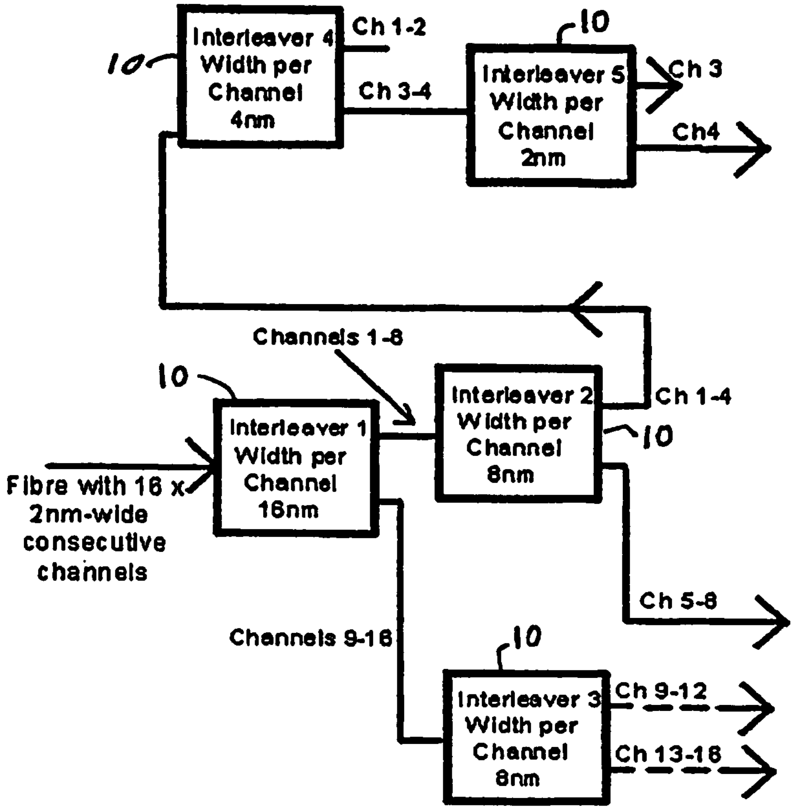


Figure 26

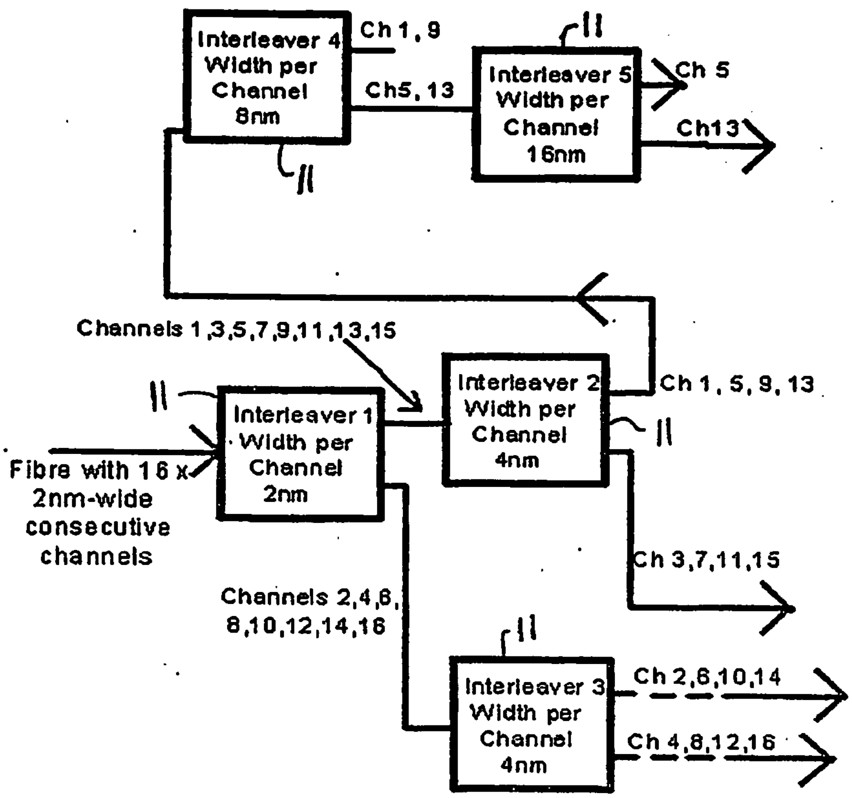


Figure 27

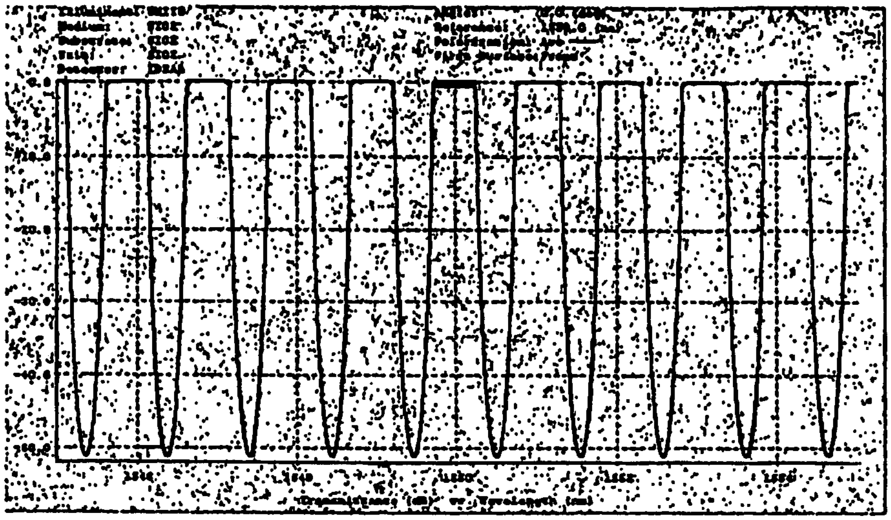


Figure 28

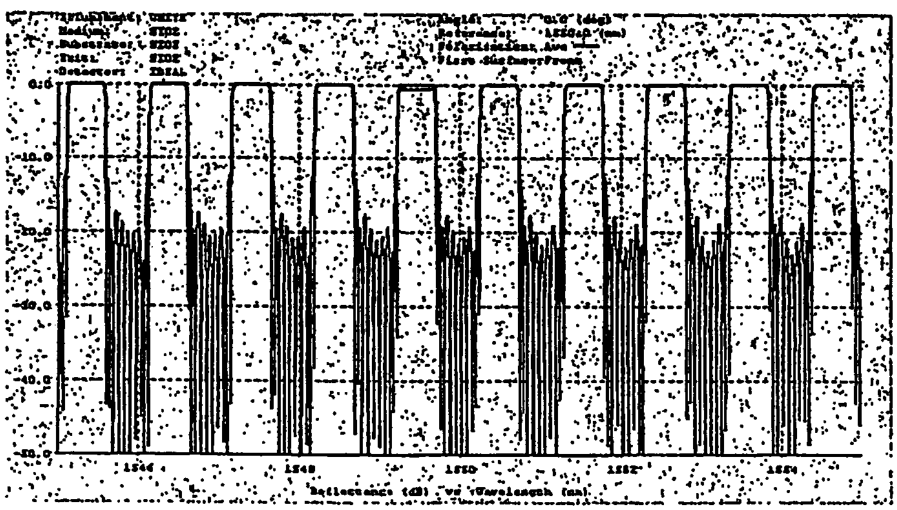


Figure 29

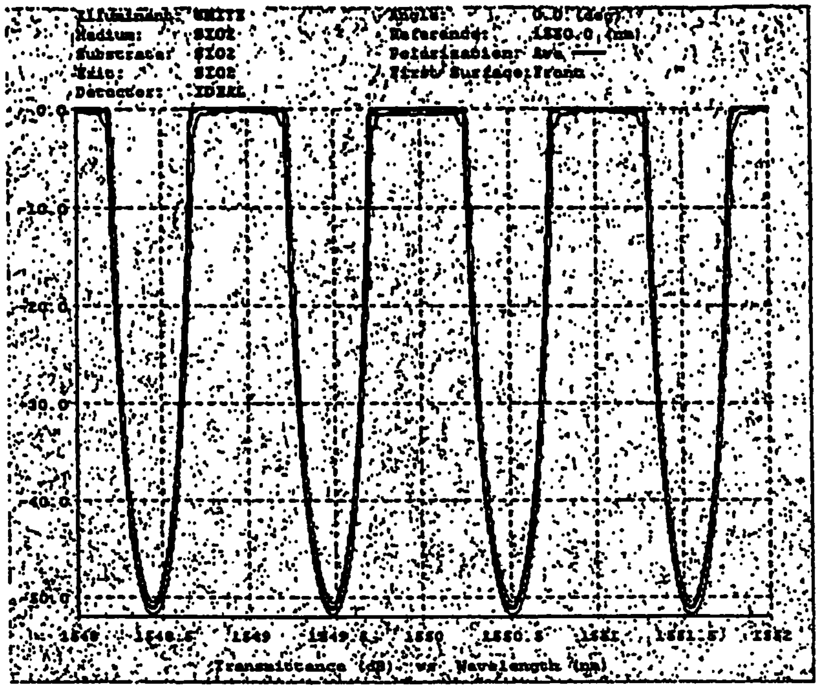


Figure 30

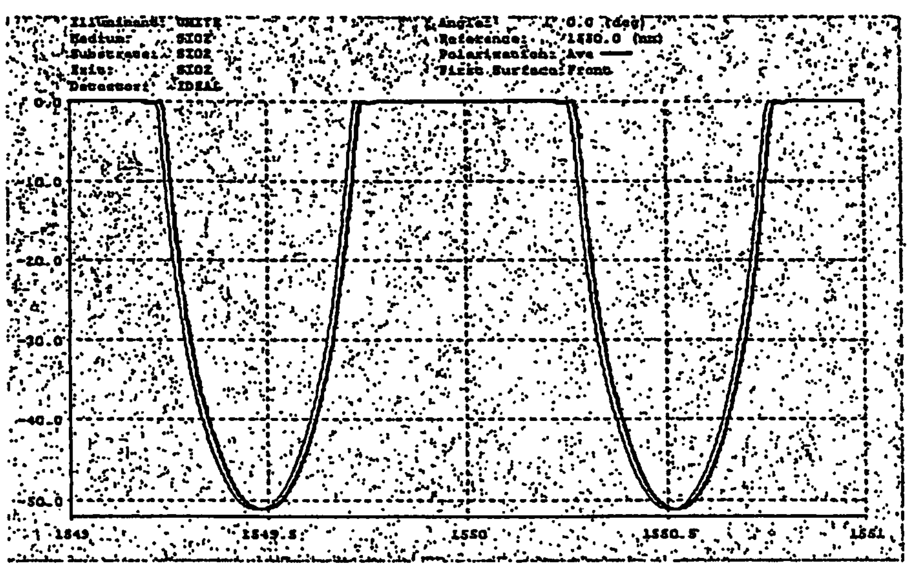
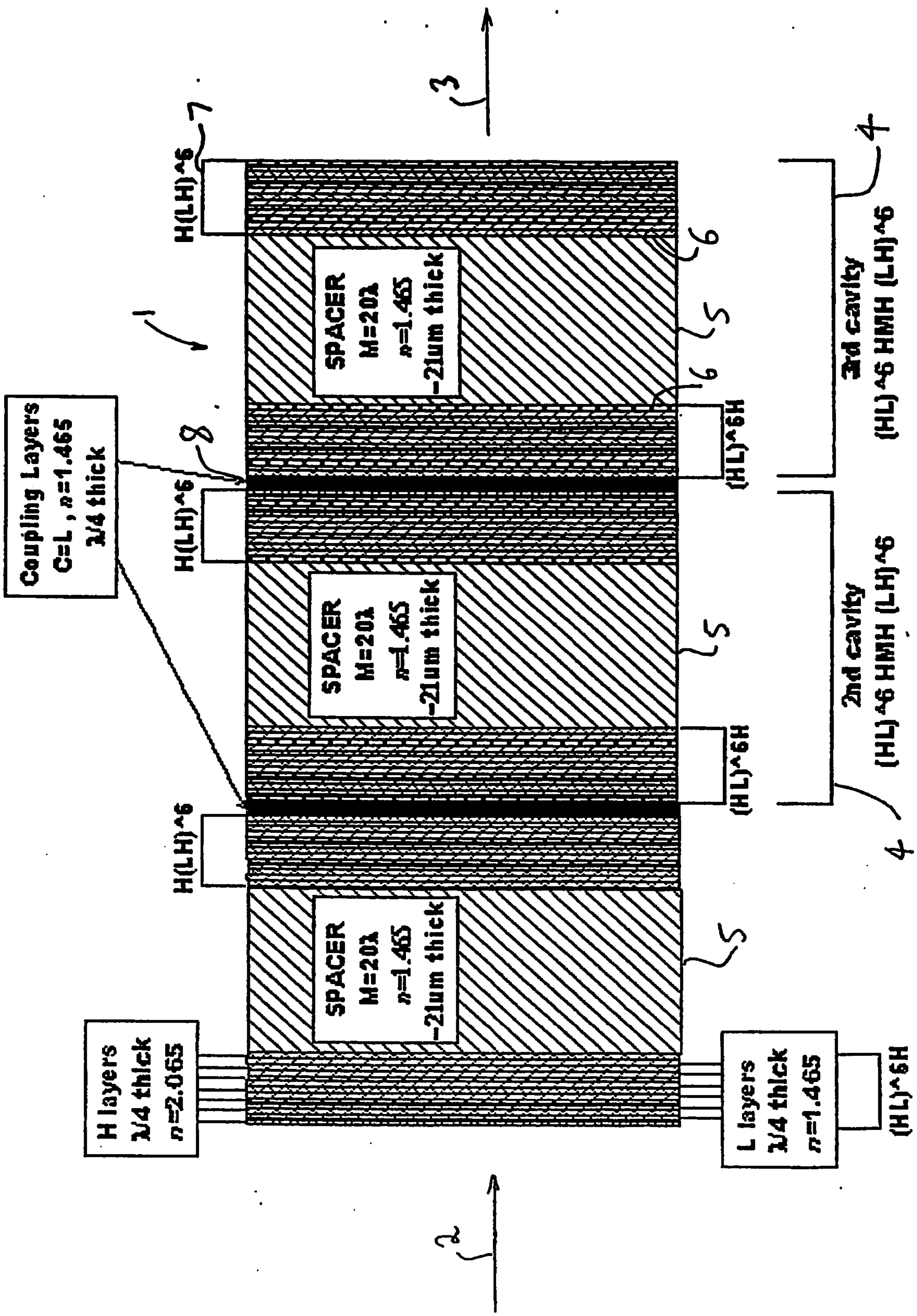


Figure 31



H layers
λ/4 thick
n=2.065
L layers
λ/4 thick
n=1.465
(HL)^6H
SPACER
M=20λ
n=1.465
~21um thick
H(LH)^6
Coupling Layers
C=L , n=1.465
λ/4 thick
(HL)^6H
SPACER
M=20λ
n=1.465
~21um thick
H(LH)^6
2nd cavity
(HL) ^6 HMH (LH)^6
(HL)^6H
SPACER
M=20λ
n=1.465
~21um thick
H(LH)^6
3rd cavity
(HL) ^6 HMH (LH)^6
1
2
3
4
4
5
5
5
6
6
7
8

Figure 32

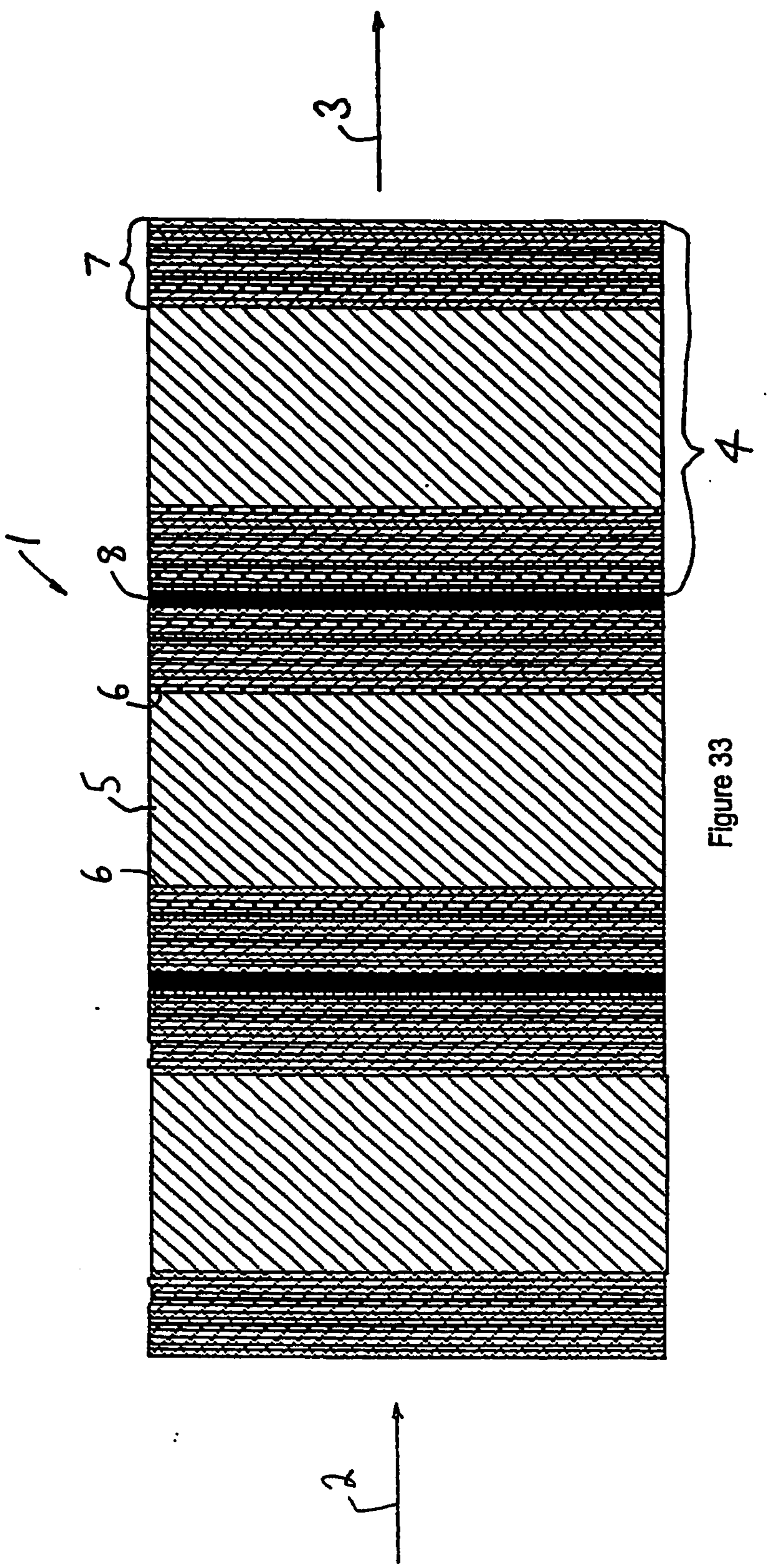


Figure 33